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ON THE EFFECT OF ACID DEPOSITION ON THE NUTRIENT ECONOMY OF SCOTS PINE

Heljä-Sisko Katainen [1] and Elina Heikkilä [2]

1) Forest Research Institute, Department of Soil Science, PL 18, 001301
Vantaa 30, Finland

2) University of Helsinki, Department of Silviculture, Unioninkatu 40 B,
00170 Helsinki 17, Finland

Abstract

The acid nitrogen and sulphur compounds affect the solubility, mobility and toxicity of soil chemical compounds. The changes in the soil nutrient economy will influence the nutrient uptake of trees. We have studied the elemental concentrations and photosynthesis of pine needles under different levels of acid deposition. According to results a moderate acidity load increases the cation content and photosynthesis of the needles. A heavy load, however, causes a decrease in the cation content and photosynthesis. The experiment was done using small seedlings. In mature trees and under more natural conditions the internal nutrient cycling may counteract to some extent the changed nutrient availability caused by external factors.

INTRODUCTION

The most important processes affecting the availability of nutrients in the soil solution are deposition from the atmosphere, weathering of minerals and cation exchange, mineralisation of organic matter and leaching of nutrients from the soil (Fig. 1).

The increased acidity of the deposition has an influence upon the availability of nutrients through these processes. The increase in the H^+-concentration in the soil solution promotes cation exchange and weathering causing increased availability of basic cations and heavy metals as well as aluminium. The elements released into the soil solution may,however, be leached away depending on the uptake by plants and the mobility of the element in question. The increased acidity may also affect mineralisation through microbial activity. The impact of acid deposition on the availability of each element is different depending on the physical and chemical characteristics of the element.

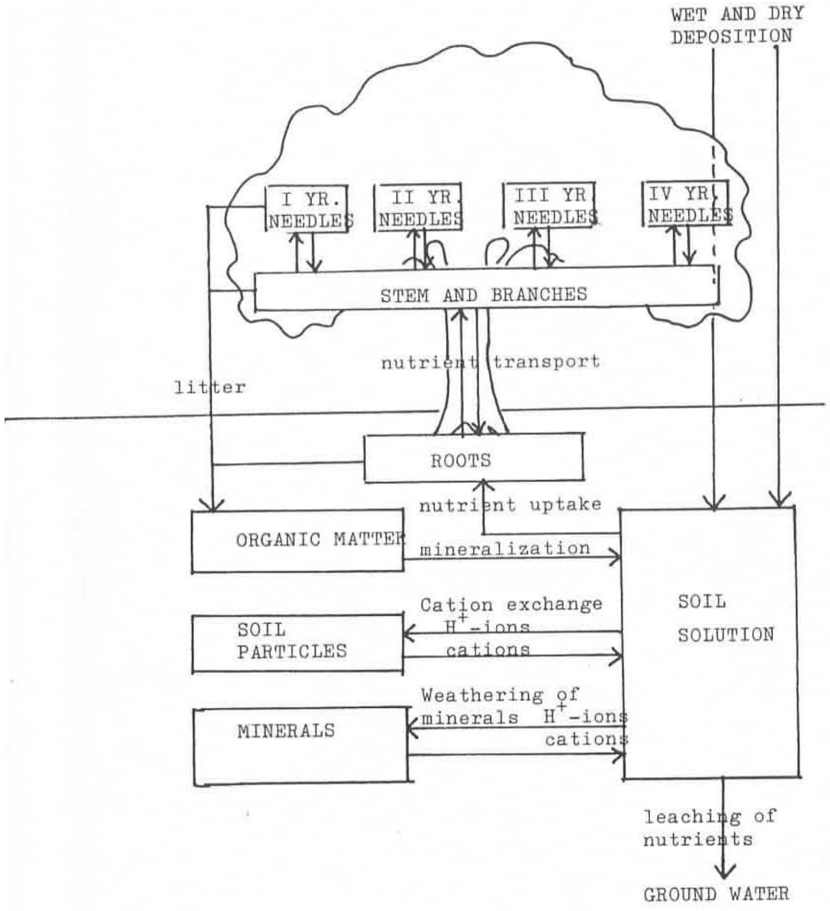

Figure 1. A simplified illustration of nutrient cycling. Arrows represent nutrient flows and boxes nutrient contents.

The supply of nutrients for physiological processes at a given time does not depend only on the availability of the nutrients in the soil solution. For example there exists tolerance mechanisms, such as selective ion uptake and immobilization of toxic elements in plants, which can reduce the negative effect of excess heavy metals in the soil solution (Bartuska and Ungar 1980). If the nutrient availability is temporarily reduced, the internal nutrient cycling can allocate nutrients from reserves to those plant parts where they are most needed.

The time scale affects the choice of processes to be studied considering the impact of acid deposition on the nutrient economy of trees.
For long-term impact the most important question is the input-output ratio of each element in the soil solution. When the short-term impact is considered also the effect of internal nutrient cycling should be taken into account.

In our experiment we studied the effect of different H^+-ion inputs on the nutrient concentrations in Scots pine needles of different age. The photosynthesis of the seedlings was also measured to find out possible relations between the change in nutrient concentrations and the photosynthetic rate.

MATERIAL AND METHODS

Soil profiles with two-year old Scots pine (Pinus silvestris L.) seedlings were exposed to simulated acid precipitation during July-September 1981. The pH of the precipitation was adjusted by H_2SO_4 to the pH values ranging from 5.5 to 2.0. Each profile received 400 ml of water every other day. The total quantity of water added in each treatment equals 340 mm during two and half months.

The soil profiles (height 30 cm, diameter 25 cm) originated from VT-type pine forest, which is a common and relatively poor forest type in Finland. The soil type is iron podsol. The profiles were placed in plastic pots and the seedlings were planted without disturbing the profiles two months before the start of the experiment.

The processes studied were leaching of nutrients from the soil, nutrient uptake by seedlings and photosynthesis. Leaching was studied by collecting the water percolating through the profile and analysing its elemental content. The nutrient uptake by seedlings was studied by analysing the elemental content of needles. One-year-old needles were analysed before and after the experiment but current-year needles only after the experiment. The samples were analysed with particle induced X-ray emission, PIXE, for P, S, K, Ca, Fe, Zn, Mn and Al. The photosynthetic rate of the current-year needles was measured after the experiment by an infraredgasanalyzer operating in a through-flow system.

RESULTS

Elemental concentrations

Watering soil profiles with simulated acid precipitation caused an increase in the concentrations of most elements in one-year-old needles.
Despite of the acidity of the treatment water (pH 4.5-2.0), the pH of the soil solution stayed between 4.5-6.0 in all treatments except the strongest one. The H^+-concentrations were lowest in the stronger treatments because of increased cation exchange.

The concentrations of phosphorous and sulphur increased most in the strongest treatments but the differences were small (Fig. 2 and 3).
Leaching of phosphorous is minimal in mineral soils. Sulphates are easily leached but the input of sulphates with the deposition exceeds leaching. The acidification of the soil solution may promote the solubility of phosphorous but on the other hand phosphorous may join with iron and aluminium to form insoluble iron-and aluminium phosphates (Russell 1961).

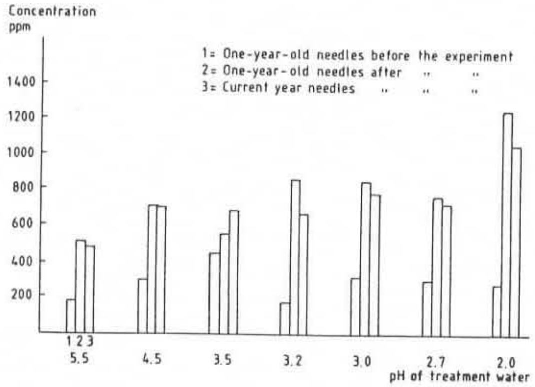

Figure 2. Concentration of phosphorous in the needles in different treatments. 1 = One-year-old needles before the experiment. 2 = One-year-old needles after the experiment. 3 = Current years needles after the experiment.

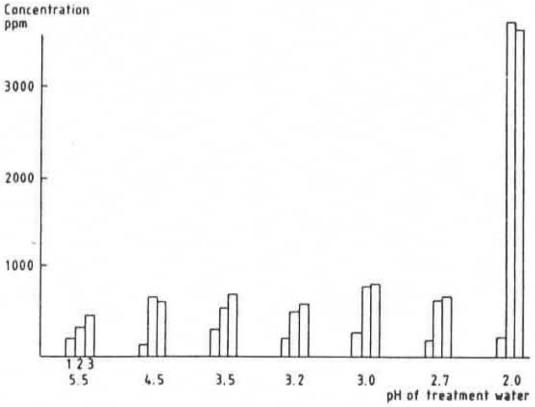

Figure 3. Concentration of sulphur in the needles in different treatments. 1, 2, and 3 as in Fig. 1.

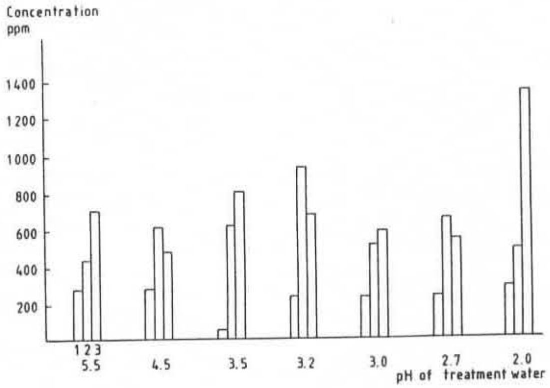

Figure 4. Concentration of potassium in the needles in different treatments. 1, 2, and 3 as in Fig. 2.

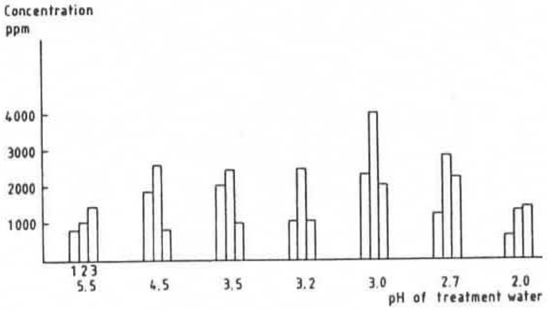

Figure 5. Concentration of calcium in the needles in different treatments. 1, 2, and 3 as in Fig. 2.

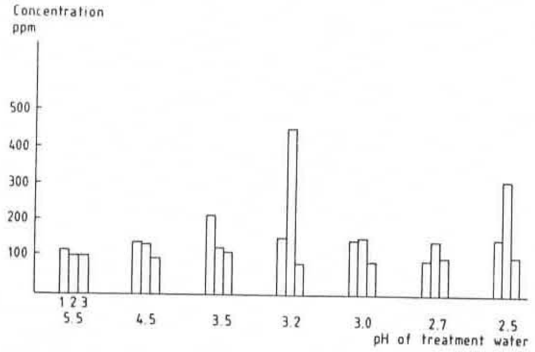

Figure 6. Concentration of iron in the needles in different treatments. 1, 2, and 3 as in Fig. 2.

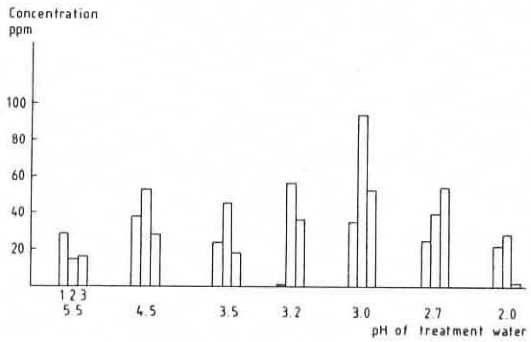

Figure 7. Concentration of zinc in the needles in different treatments. 1, 2, and 3 as in Fig. 2.

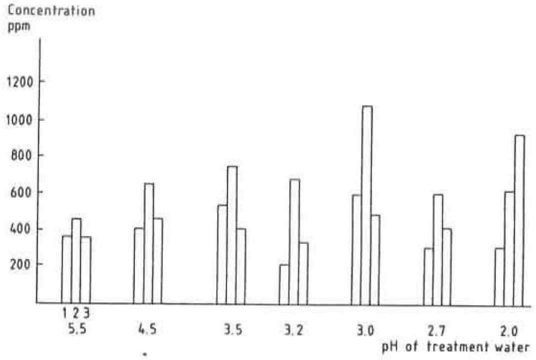

Figure 8. Concentration of manganese in the needles in different treatments. 1, 2, and 3 as in Fig. 2.

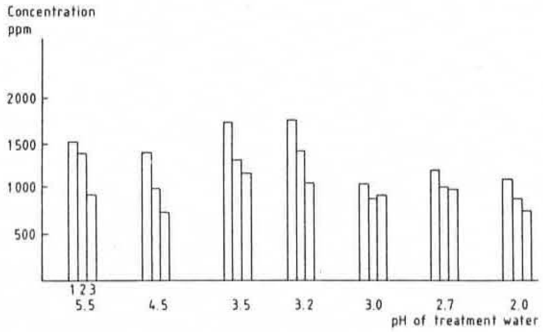

Figure 9. Concentration of aluminium in the needles in different treatments. 1, 2, and 3 as in Fig. 2.

The acid input caused a distinguished increase in the concentration of basic cations such as potassium and calcium (Fig. 4 and 5) because of promoted cation exchange. For K^+ the greatest increase was in treatments with water having pH 3.2-3.5. The high concentration of K^+ in the strongest treatment in the current-year needles may partly be explained by the mobilization of K^+ from the older needles. K^+ is easily transported from stores to growing plant parts. Because of the cycling and translocation pattern of K^+ as well as active uptake acid precipitation is not likely to cause leaching of K^+ during the growing season. Only in the long run K^+ availability may decrease in well weathered sandy and organic soils because of leaching during periods with little uptake.

Ca^{2+}-concentrations in the needles increased most in the strongest treatments (pH 3.2-2.5). There was less Ca^{2+} in the younger needles than in the older ones. This can be due to the poor mobility of Ca^{2+} inside the plant (Loneragan and Snowball 1969). The leaching losses of Ca^{2+} are high in acid mineral soils but Ca^{2+} is needed in fairly small amounts by plants. Wallace et al (1966) suggested that Ca^{2+} is mainly needed to detoxify divalent metal cations.

The acid input increased also the concentrations of heavy metals such as iron, zinc and manganese (Fig. 6, 7 and 8). The solubility of these metals is strongly pH dependent. Iron and zinc compete with each other in nutrient uptake (Lingle et al 1963), which may be the reason for the low zinc concentration in the seedling with high iron uptake. Heavy metals are toxic to most plants in high concentrations. Some tolerance mechanisms, such as selective ion uptake and immobilization of toxic elements in plants can, however, reduce the negative effect of heavy metals.

The solubility of aluminium compounds increases strongly when the pH of the soil solution is less than 5 (Evans and Kamprath 1970).Aluminium accumulates to roots where it disturbs ion uptake and root growth. In our experiment the needle concentrations of aluminium decreased in all treatments (Fig.9). Leaching of aluminium was remarkable in the strongest treatment.

Photosynthesis

The photosynthetic rates of seedlings with high cation concentrations in the needles were higher than that of the control seedling (Fig. 10). The seedling in the strongest treatment showed hardly any photosynthesis.The reason might have been the toxic sulphur concentration in the needles (3600 ppm).

The seedlings were growing and photosynthesis measured in similar environmental conditions. However, it was not possible to estimate the differences in photosynthesis caused by genetic factors. The photosynthetic rate was measured only after the experiment because pine needles grow untill August.

DISCUSSION

The results received from the experiment can not be directly generalized to concern field conditions. The possible changes in the nutrient economy of trees caused by acid deposition is not as easily detectable in the field as in simplified simulation situations. On the other hand, by making the studied system more simple it is possible to understand better the influence of individual factors on the availability and uptake pattern of nutrients in plants exposed to acid precipitation impact.

The simplifications of the simulated deposition and the studied plant-soil system should be considered when the experiment is compared with the field situation.
The acidification of the precipitation has been gradual over wide areas and it is impossible to find comparable control areas. In the field the acidity and duration of the precipitation vary in both time and space. These are important factors affecting the reaction ways and rates of H^+-ions in soil.

Compared with the experiment, in field conditions the mean acidity of the deposition corresponds to the moderate treatments.Also the precipitation frequency during the growing period is usually smaller in the field. Both of these factors are likely to decrease the acidification rate of the soil solution in the field compared with the experiment. The simulated precipitation did not contain any nitrogen. However, the deposition of nitrogen in boreal forests far exceeds leaching and may thus increase productivity.

The seedlings were growing in a limited soil volume without any nutrient applications during the experiment. This obviously caused a fast rate of depletion of certain nutrients in the profiles because the volume of soil for cation exchange and weathering was limited. Also the experiment period was very short compared with the mineralisation rates.

Sampling of needles should take place at much shorter intervals than in the experiment to study the nutrient dynamics in detail. Studying small seedlings with a limited number of needles frequent sampling is not possible, however. In small seedlings the internal nutrient cycling is rather limited compared with mature trees, in which the internal cycling obviously plays an important role. In a natural ecosystem those nutrients that are most limiting are cycled more efficiently than the abundant ones.

As a conclusion it can be stated that the application of needle analysis to detect changes in the nutrient availability caused by acid deposition may be a useful method in a simulating experiment. However,in field conditions this method has severe limitations.To find out the possible effects of acid deposition in the field ,it is necessary to consider the ion cycling in the whole ecosystem as well as inside the plants.

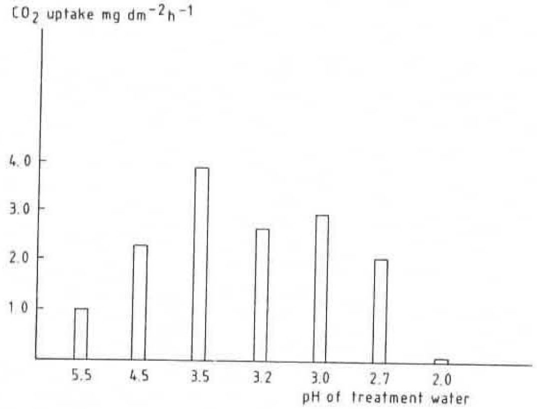

Figure 10. The photosynthetic rate of current needles at PAR 1400 $\mu E\ m^{-2}s^{-1}$

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